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PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

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RECENT AIRPORT DESIGN AND DEVELOPMENT

By Philip A. Hahn

CITY PLANNING AND AIR TRANSPORT DIVISIONS

Headquarters of the Society
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"Proceedings-Separates" of value or significance to readers in various fields are here listed, for convenience, in terms of the Society's Technical Divisions. Where there seems to be an overlapping of interest between Divisions, the same Separate number may appear under more than one item. For a description of papers open to discussion refer to the current issue of *Civil Engineering.*

Technical Division	*Proceedings-Separate Number*
Air Transport	163, 172, 173, 174, 181, 187, 191, 194, 195, 196 (Discussion: D-75, D-93, D-101, D-102, D-103, D-108, D-121)
City Planning	154, 164, 167, 171, 172, 174, 177, 191, 194, 196 (Discussion: D-86, D-93, D-99, D-101, D-105, D-108, D-115, D-117, D-138)
Construction	161, 162, 164, 165, 166, 167, 168, 181, 183, 184, 198 (Discussion: D-101, D-102, D-109, D-113, D-115, D-121, D-126, D-128, D-129, D-134, D-136, D-145)
Engineering Mechanics	157, 158, 160, 161, 162, 169, 177, 179, 183, 185, 186, 193, 197, 199 (Discussion: D-34, D-49, D-54, D-61, D-96, D-100, D-122, D-125, D-126, D-127, D-128, D-135, D-134, D-136, D-145)
Highway	150, 152, 155, 163, 164, 166, 168, 185, 190, 191, 192, 195, 198, 199 (Discussion: D-103, D-105, D-108, D-109, D-113, D-115, D-117, D-121, D-123, D-128, D-129, D-134, D-138)
Hydraulics	154, 159, 164, 169, 175, 178, 180, 181, 184, 186, 187, 189, 193, 197 (Discussion: D-91, D-92, D-96, D-102, D-113, D-115, D-122, D-123, D-135)
Irrigation and Drainage	153, 154, 156, 159, 160, 161, 162, 164, 169, 175 178, 180, 184, 186, 187, 189, 190, 197 (Discussion: D-102, D-109, D-117, D-129, D-135)
Power	139, 141, 142, 143, 146, 148, 153, 154, 159, 160, 161, 162, 164, 169, 175, 178, 180, 184, 186, 189, 190, 192, 193, 197 (Discussion: D-109, D-112, D-117, D-129, D-135)
Sanitary Engineering	55, 56, 87, 91, 96, 106, 111, 118, 130, 133, 134, 135, 139, 141, 149, 153, 166, 167, 175, 176, 180, 187, 193 (Discussion: D-99, D-102, D-112, D-117, D-135)
Soil Mechanics and Foundations	43, 44, 48, 94, 102, 103, 106, 108, 109, 115, 130, 152, 155, 157, 166, 177, 190, 192, 195 (Discussion: D-108, D-109, D-115, D-129, D-134)
Structural	145, 146, 147, 150, 155, 157, 158, 160, 161, 162, 163, 164, 165, 166, 168, 170, 175, 177, 179, 181, 182, 183, 185, 188, 190, 195, 198, 199 (Discussion: D-61, D-66, D-72, D-77, D-100, D-101, D-103, D-109, D-121, D-125, D-126, D-127, D-128, D-134, D-136, D-145)
Surveying and Mapping	50, 52, 55, 60, 63, 65, 68, 121, 138, 151, 152, 172, 173 (Discussion: D-60, D-65, D-138)
Waterways	123, 130, 135, 148, 154, 159, 165, 166, 167, 169, 181 (Discussion: D-19, D-27, D-28, D-56, D-70. D-71, D-78, D-79, D-80, D-112, D-113, D-115, D-123, D-135)

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AMERICAN SOCIETY OF CIVIL ENGINEERS

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PAPERS

RECENT AIRPORT DESIGN AND DEVELOPMENT

By Philip A. Hahn[1]

Synopsis

The recent developments and trends in airport design and construction are common knowledge to the engineer. This paper presents the reasons for these trends and developments. These advances have been based on a desire to follow engineering principles which are basically sound and economically wise in planning, surveying, and structural endeavors. There is still another important factor which controls airport engineering and that is the need for providing the necessary aeronautical requirements to insure the safe operation of aircraft in the vicinity of the airport, in turning zones or areas, in the approaches, and on the airport.

Airport Size and Type

Since the adoption of the Federal Airport Act of 1946,[2] several changes have been made by the Civil Aeronautics Administration, United States Department of Commerce (CAA), in airport nomenclature and design criteria. One of the first major changes was to dispense with the categorization of airports as Class 1, 2, 3, and so on. This classification was based on the length of the longest runway at each airport. The situation was further confused because the CAA Class 1 was the smallest airport, whereas Class 1 was the largest airport in the classification system used by the military air groups. The revised classification system categorizes the various airports by the type of air activity or service that occurs at the airport. Therefore, airports are identified as follows:

Personal.—For light aircraft usage at small community and urban areas.

Secondary.—For larger aircraft usage, up to a gross weight of 15,000 lb, engaged in nonscheduled flying activities.

Note.—Written comments are invited for publication; the last discussion should be submitted by **November 1, 1953.**

[1] Chf. Airport Eng. Div., Office of Airports, Civ. Aeronautics Administration, U. S. Dept. of Commerce, Washington, D. C.

[2] *Public Law 377*, 79th Cong., 2d Session, Washington, D. C.

Feeder.—To serve all planes up to certificated feeder airlines.

Trunk.—For the servicing of intermediate communities on airline trunk routes.

Express.—To serve relatively large cities or junction points on trunk routes.

Continental.—For the servicing of aircraft making long nonstop domestic flights.

Intercontinental.—Airports that are terminal points for long international flights.

Intercontinental Express.—Airports that serve the highest type of transoceanic flights.

Coupled with these categories is the CAA Technical Standard Order (TSO) N-6a, which indicates the maximum extent of runways, taxiways, and landing strips for which the government will afford federal aid. Also listed in TSO N-6a are the correction formulas as to runway length which must be made for airport elevations, temperature, and runway gradient. In many cases shorter lengths will be satisfactory for the type of service encountered. The issuance of TSO N-6a was necessary in eliminating confusion as to the dimensional sizing of runways to be applied to airport developments at various locations and areas. It was only after extensive coordination with the entire aviation industry had been achieved that TSO N-6a was issued.

Airport Configuration

Airport configuration—as related to the number and orientation of runways, taxiways, lead-off taxiways, warm-up aprons, parking aprons, and terminal areas—is a very vital item to be considered in the development of airports and, more particularly, in the development of master plan layouts. Too much emphasis cannot be placed on the need for careful, detailed, and prolonged studies for the master plan. A review of airport configurations indicates that, whereas certain airports are sound and very usable by the standards of engineering and aeronautics, many of them do not have maximum efficiency. To emphasize the need for good airport configuration, the CAA issued a policy governing the number of runways to be established at airport projects receiving federal aid. The basic aim of this policy is to construct, at existing and proposed airports, traffic bearing runways which will provide a maximum degree of utilization. This policy is commonly known as the "one-runway" policy. Actually, this is a misnomer because the policy does not curtail an airport to one bi-directional runway, but does emphasize that not more than one runway should be constructed at a site unless traffic warrants the development of two or more runways. The traffic capacity of a single runway has been established as 40 operations per peak-hour per runway, whether the operations are landings, take-offs, or a combination of landings and take-offs. If it is determined that there is a need for multiple runways at an airport, the most efficient orientation pattern would be a parallel arrangement with a separation of at least 3,000 ft and preferably 4,000 ft. The reason for such a separation is to provide maximum efficiency in the operation of aircraft under all weather conditions, during both landings and take-offs. In adverse weather, landings and take-offs can

be conducted with the aid of radar facilities and other electronic devices which are essential to speeded-up instrument operations. Any deviation from the ideal configuration will decrease the efficiency or capacity of the runways.

Modified configurations consisting of nonintersecting divergent runways separated by at least 700 ft in the apex area and diverging at an angle of at least 15° can approach the ideal under some operational conditions. However, intersecting runway patterns afford poor efficiency because they provide only a slight increase in capacity over a single runway and, therefore, should be avoided.

In certain instances the land area will restrict developments and can reduce operational efficiency, but the goal should be to adapt that system which provides maximum efficiency under the existing conditions. Once the runway layout is established, careful consideration must be given the configuration and location of taxiways (especially lead-off taxiways) and the size and location of run-up aprons at runway ends to provide for a rapid clearance of aircraft from the runways. A preliminary study of lead-off taxiway and run-up apron configurations was conducted from 1949 to 1951.

To make this study, certain airports throughout the United States were selected on the basis of the existing configuration and traffic density, which provided the desired variations in local conditions and traffic. Various aspects were explored to determine the effect of factors on the landings with respect to touchdown, turnoff, and time on the runway. These studies revealed that—

1. Data on night or day landings were essentially the same.
2. Data for instrument or visual landings showed no notable difference.
3. Landing roll, in many instances, was influenced by the intended destination at the airport.
4. The available length of runway had no apparent effect on the point of touchdown or landing roll distance.
5. The length of the landing roll was approximately inversely proportional to the touchdown distance.
6. Angular lead-off taxiways reduce the operating time of aircraft on the runway as opposed to the use of right-angle turnoffs. Angularity between 30° and 60° does not reflect any difference in time on the runway.

Less than 1% of the aircraft made the touchdown within 100 ft of the threshold, but 93% of the aircraft "touched down" within a distance of 1,500 ft. Table 1 shows the average turnoff distances from the threshold for various aircraft. It was found that relatively few aircraft turn off the runway in less than 2,000 ft from the threshold and that practically all aircraft complete the landing roll before reaching a point 5,000 ft from the threshold, except in cases of excessive overshooting. The optimum locations of lead-off taxiways have been determined as 2,500 ft, 3,500 ft, and 4,500 ft from the threshold. These locations are somewhat flexible and should be adjusted to fit the runway length, with the realization that exits located less than 2,000 ft, or more than 5,000 ft, from the threshold are of little value.

A review of run-up apron data revealed that, during off-peak periods of traffic, the average run-up time was generally in proportion to the size of the

airport. The data also show that the average run-up time increased as the traffic increased and that, in periods of peak traffic, run-up time was about equal for all types of aircraft. The size of the run-up apron required at each location will depend principally on the rate of peak traffic on a particular runway. For peak traffic on a runway serving both landings and take-offs, an average run-up time of 10 min, as compared with 6 min for runways serving take-offs only, should be used as a basis for determining the run-up apron size.

Table 2 is a guide for the design of apron lengths. The apron should not be designed to accommodate less than two large airplanes nor more than five large airplanes. It is desirable to locate the run-up aprons in a position as close as possible to the intersection of the runway and the taxiway and still fulfil safe clearance requirements.

Another vital factor to consider in the over-all configuration of the airport is whether the proposed arrangement lends itself readily to the fulfilment of the criteria for determining obstructions to air navigation with particular reference to turning zones and approach areas as they affect instrument and visual operations. The latter criteria are all contained in CAA TSO N-18. The drawing contained in this order, frequently referred to as Drawing No. 814, depicts the various phases of imaginary surfaces and limiting heights above ground for all types of airports. The intricacy of the arrangement of the drawing has precipitated adverse comments as to the difficulty with which it can be applied and interpreted. The fact that all airports of all categories are described in the one drawing may give rise to such comments. However, when the requirements of the drawing are applied to an individual airport, it will be found that many of the apparent mathematical and developmental intricacies resolve themselves into relatively easy problems. A simple visual concept of TSO N-18 is that of an ordinary kitchen pie plate. It is not anticipated that each requirement may be met in every instance. However, careful thought should be given its application in order to minimize intricate landing procedures with particular reference to those necessary for instrument operations.

TABLE 1.—DISTANCE FROM THRESHOLD TO TURNOFF

Airplane type	Distance, in feet	
	Minimum	Average
Single engine	1,000	2,750
DC-3	1,500	2,950
Convair 240	1,650	3,300
Martin 202	2,200	3,500
DC-4	2,200	3,400
DC-6	2,175	3,400
Constellation	2,225	3,800
Boeing 377	2,275	3,700
All aircraft	1,000	3,200

TABLE 2.—THE EFFECT OF OPERATING CONDITIONS ON APRON LENGTHS

Runway system	Rate of take-off per hour	Apron length, in feet
Take-offs and landings	15	200
	20	300
	30	500
Take-offs only	15	200
	20	200
	30	300
	40	400

When developing master plan layouts, it is important to provide areas for the location of all electronic aids necessary for the navigation of aircraft, whether these aids occur within or without the confines of the airport boundaries.

Much interest has been expressed and a great deal of curiosity aroused as to the effects of the operation of jet aircraft on runway, taxiway, and apron layouts of an airport. All statements regarding special requirements as a result of jet transport operations are necessarily vague since the operation of jet transports has been extremely limited, but it may be assumed that any changes from existing requirements will be of a minor nature. Until definite information on the effect of jet aircraft on runways becomes available, the CAA does not plan to introduce any changes in airport design standards. In this connection, however, studies leading to the improvement of standards will be made and are being given special consideration.

Pavement Design

In the early days of airport development it was felt that highway pavement design methods would suffice for aircraft loadings. This was a reasonable assumption for the type of aircraft in use at the time. However, as airport experience broadened, standards were revised to allow for the specialized requirements of airport pavements. Standards were also revised to provide for the greater strength needed to support the ever-increasing loads superimposed on the pavements by new developments in aircraft design. These revisions have been made from studies of experimental investigations, accelerated traffic tests, and pavement performance under service conditions.

Design based on performance is generally rule-of-thumb. The users of the methods mentioned do not claim them to be the final answer, but the fact remains that they are the most reliable available at the present time. Satisfactory methods for determining pavement thickness requirements, on the basis of stress analysis within the pavement and in the supporting subgrade, have not been developed. Even the Westergaard method, which has been widely accepted in the field of rigid pavement design, must be modified in accordance with the behavior of pavements in service.

Studies of pavement performance have yielded information regarding the relative importance of static, dynamic, and impact loads. The studies have also furnished information on the pavement areas that are most critical from the standpoint of aircraft use, as well as data on the relationship between the stability of the soil, the magnitude of the applied loads, and the pavement thickness.

Each governmental agency charged with the development of design standards has prepared procedures to be followed by the engineers in that particular group. Although these methods differ in details, they are basically similar in so far as soils are classified or indexed according to certain physical properties determined by specified laboratory or field tests. From observed behavior and a knowledge of climatic variables at the site, pavement thickness requirements are estimated. In general, the determination is made from a series of curves which gives the relationship between pavement thickness, wheel loading, and subgrade soil. The validity of these design curves are being checked continuously against pavement performance, and adjustments are made if the curves are found to be in error. The reliability of the design depends on the

proper interpretation of test results and good judgment in predicting the behavior of the soils under the moisture and climatic conditions encountered.

There are obvious drawbacks to a design procedure which depends almost entirely on a few soil tests and a great deal of experience. It would be more logical if it were possible to determine accurately the bearing power of subgrade soil and then to analyze the pavement requirements on the basis of a distribution of stresses in the pavement and in the soil. However, because of the changes in stability of a given subgrade soil produced by variations in moisture, climate, and the arrangement of the soil layers, a method of determining a definite or absolute value of bearing strength remains to be decided. This lack of a reliable value for the bearing strength is the most serious obstacle to the development of the analytical methods of design. Until the bearing strength of the subgrade soil can be determined and controlled, it will be necessary to continue using the existing methods of estimating this strength on the basis of observed pavement behavior correlated with subgrade conditions. As of 1952 these methods are a satisfactory guide to pavement design, as has been proved by the performance of pavements constructed in accordance with these design criteria.

The development of acceptable analytical methods is progressing as a result of extensive investigations conducted by the CAA; the Bureau of Public Roads, United States Department of Commerce; the Corps of Engineers, United States Department of the Army; and the Bureau of Yards and Docks, United States Department of the Navy. These investigations are producing accurate information on the distribution of stresses in subgrade soils under loads applied at the surface and on the ways and means of controlling the moisture and volume changes that occur in soils, so as to provide support of a more permanent and uniform nature.

Operation of jet aircraft has raised many questions concerning the performance of airport pavements subjected to fuel spillage and high exhaust temperatures. It is believed that spillage is not a serious problem. However, the effect of the jet blast is significant. Observations made on fields where jet aircraft operations are of a sufficient magnitude so as to furnish performance data disclose that the areas seriously affected are small in extent and are confined to locations where sustained run-up periods occur, thus subjecting the pavement to sustained blasts. No damage has been observed so long as the jet aircraft is in motion.

The effect of the blast on the pavement will depend on the design of the aircraft with respect to the velocity of the blast and the angle of the exhaust. As the direction of blast approaches the horizontal, the less important the blast becomes, so far as pavements are concerned. Because of this, observations of transport types of jet aircraft indicate that there is no detrimental effect on the airport pavement.

Terminal Buildings and Area

In the development of terminal areas and buildings, the goal is to determine facility sizing and layout criteria and to develop basic site planning and layout considerations for the entire building area. To be successful and acceptable,

such criteria should not force architectural design by formula, nor should the criteria lean toward "standard" or "stereotyped" plans. There is no attempt to encroach on the designers' prerogatives relating to freedom of architectural design and treatment.

Analyses of passenger and visitor activities at a large number of airports of varying passenger volume revealed a fairly consistent pattern of relationships between total annual passengers and the number of passengers that would have to be accommodated during a typical peak hour. In addition to the passenger activity patterns, significant data were found on the number of visitors and patrons of the concessions. Therefore, the peak-hour passenger is the common denominator in determining the area requirements for airline, public, and concessionaire space needs. Along with this information, passenger volume forecasting methods allow extrapolation of data in order that terminal buildings may be sized to accommodate passenger volumes ten years in advance of the construction of the facility. This extrapolation results in initial oversizing of the building, but it allows for increase in passenger volume without requiring additions to the structure for an extended period. Consistent functional relationships exist between the various spaces and activities in a terminal building for the processing of passengers and the accommodation of the visitors. These relationships have been so distorted that confusion and delays befell the "using" public, operational inefficiencies developed for the airlines, and financial losses were incurred by the concessionaires and airport owners. The new approach to this situation is the development of schematic space relationship diagrams and flow diagrams which show graphically the accepted relationships between the functions and spaces of a terminal building. These diagrams do not restrict the freedom of the designer in the development of an individualized scheme. However, the schemes have done much toward making industry agree on the basic principles of terminal building operation, and great strides have been taken toward this goal.

The matter of site planning and development has been treated in much the same manner as have been the space relationships—through the development of area use diagrams which schematically depict accepted relationships of the various operational areas of an airport. Here again, predesign has been purposely avoided, and the functional disposition of the required activities and their relationships to surrounding areas and associated activities have been indicated.

There has been an attempt to bring out the "whats" and leave the "hows" to the designer. Economic practicability, amortization potentialities, and functional efficiency should be the prime considerations in allocating space. However, expansibility and flexibility are the prime considerations in the design and construction of airport terminal buildings.

Airport Lighting

Great strides have been made in improving airport lighting facilities since 1946. The most important improvement has been the elevated runway and taxiway lights and their subsequent use as replacements for the semiflush-type lights.

The semiflush lights presented many problems which are relatively insolvable. For example, it is almost impossible to keep the system operative because most of the unit is below ground. This condition made it extremely difficult to keep the system dry, and, consequently, many shorting outs occurred. Another difficulty of the system is that bare current-carrying parts of the unit are below ground, making electrical maintenance a never-ending job. The optical system was of such a character that the light beams were literally "bent around a corner" to allow for pilot observation. Also, because of the low height of the unit, the light beams were readily obscured by dirt, snow or even a 4-in. growth of grass.

With the elevated type of light, from 13 in. to 30 in. above ground, any current-carrying parts of the unit below ground are sealed into watertight housings. This sealing eliminates all the shorting out encountered with semiflush lights. With the same wattage lamp, the efficiency of the optical system is five times greater.

There appear to be two solutions which offer good possibilities for the protection of underground cable from lightning strikes. The first is to install a counterpoise system, consisting of a bare copper conductor installed in the same trench with the underground cables and about 4 in. above the cables. This bare copper circuit is then connected to a ground rod at several points around the airport so that any lighting surges in the vicinity of the airport will be carried away from the underground lighting cables and off to a good established ground. The second solution is quite similar to the first, except that the underground cables are manufactured with a shielding metallic tape. This metallic tape completely encircles the underground cable and protects it in the same manner as the counterpoise system. Those airports that have installed cable with a metallic shielding tape have had some encouraging results.

One of the greatest sources of trouble in an airport lighting system has been the inability to obtain good splices during construction. To overcome this situation, rubber-covered insulating transformers have been developed with leads that have special rubber-covered connectors for underground circuits. However, because the rubber covering is moulded directly to the transformer windings, the potential for moisture entering the equipment is eliminated.

Because efficient lighting equipment is so important as a visual aid to pilots in the approaches as well as on the ground, there is a constant search for improvement of the over-all picture.

Conclusion

It is apparent that aviation is an important and expanding industry. Consequently, engineers cannot remain stagnant with outdated criteria for the development of aircraft facilities, but must seek improved standards and designs. Engineers who are, or will be, concerned with airport development, therefore, must keep abreast of the advances in design suggestions and standards.

CURRENT PAPERS

Proceedings-Separate Number	Title and Author	Discussion closes*
159	"Development of a Flood-Control Plan for Houston, Tex.," by Ellsworth I. Davis	June 1
160	"Ice Pressure Against Dams: Studies of the Effects of Temperature Variations," by Bertil Löfquist	June 1
161	"Ice Pressure Against Dams: Some Investigations in Canada," by A. D. Hogg	June 1
162	"Ice Pressure Against Dams: Experimental Investigations by the Bureau of Reclamation," by G. E. Monfore	June 1
163	"A Comparison of Design Methods for Airfield Pavements," Progress Report of the Committee on Correlation of Runway Design Procedures of the Air Transport Division	June 1
164	"Water Supply Engineering," Report of Committee on Water Supply Engineering of the Sanitary Engineering Division for the Period Ending September 30, 1951	July 1
165	"Design Curves for Anchored Steel Sheet Piling," by Walter C. Boyer and Henry M. Lummis, III	July 1
166	"The Design of Flexible Bulkheads," by James R. Ayers and R. C. Stokes	July 1
167	"Sewage Disposal in Tidal Estuaries," by Alexander N. Diachishin, Seth G. Hess, and William T. Ingram	July 1
168	"Special Design Features of the Yorktown Bridge," Maurice N. Quade	July 1
169	"Rating Curves for Flow over Drum Gates," by Joseph N. Bradley	Aug. 1
170	"Rapid Computation of Flexural Constants," by Thomas G. Morrison	Aug. 1
171	"Unified Mass-Transportation System for New York," by William Reid	Aug. 1
172	"Aeronautical Charting and Mapping," by Charles A. Schanck	Aug. 1
173	"Electronic Devices for Air Transport," by F. B. Lee	Aug. 1
174	"Zoning Maps for Airports," by Benjamin Everett Beavin, Sr.	Aug. 1
175	"Design of Side Walls in Chutes and Spillways," by D. B. Gumensky	Aug. 1
176	"Advances in Sewage Treatment and Present Status of the Art," Progress Report of the Committee of the Sanitary Engineering Division on Sewerage and Sewage Treatment	Sept. 1
177	"Earthquake Stresses in Shear Buildings," by M. G. Salvadori	Sept. 1
178	"Rainfall Studies Using Rain-Gage Networks and Radar," by H. E. Hudson, Jr., G. E. Stout, and F. A. Huff	Sept. 1
179	"Stiffness Charts for Gusseted Members Under Axial Load," by John E. Goldberg	Sept. 1
180	"A Direct Step Method for Computing Water-Surface Profiles," by Arthur A. Ezra	Sept. 1
181	"Slackwater Improvement of the Columbia River," by O. E. Walsh	Oct. 1
182	"Hipped Plate Analysis, Considering Joint Displacement," by Ibrahim Gaafar	Oct. 1
183	"Group Loadings Applied to the Analysis of Frames, by I. F. Morrison	Oct. 1
184	"Dam Modifications Checked by Hydraulic Models," by E. S. Harrison and Carl E. Kindsvater	Oct. 1
185	"Nonelastic Behavior of Bridges Under Impulsive Loads," by S. J. Fraenkel and L. E. Grinter	Oct. 1
186	"Settling Rates of Suspensions in Solids Contact Units," by A. A. Kalinske	Oct. 1
187	"The Equivalent Rectangle in Prestressed Concrete Design," by John J. Peebles	Oct. 1
188	"Laminar to Turbulent Flow in a Wide Open Channel," by W. M. Owen	Oct. 1
189	"Snow Hydrology for Multiple-Purpose Reservoirs," by H. S. Riesbol	Nov. 1
190	"Analysis of Corrective Actions for Highway Landslides," by R. F. Baker	Nov. 1
191	"The Engineer's Role in Metropolitan Traffic Planning," by Lloyd Braff	Nov. 1
192	"Relief Well Systems for Dams and Levees," by W. J. Turnbull and C. I. Mansur	Nov. 1
193	"Velocity Measurement of Air-Water Mixtures," by L. C. Straub, J. M. Killen, and O. P. Lamb	Nov. 1
194	"City Planning Techniques," by Russell H. Riley	Nov. 1
195	"Special Procedures for Pavement Design," by L. A. Palmer	Nov. 1
196	"Recent Airport Design and Development," by Philip A. Hahn	Nov. 1
197	"Friction Factors for Turbulent Flow in Pipes," by Edward F. Wilsey	Nov. 1
198	"Live Loading for Long-Span Highway Bridges," by R. J. Ivy, T. V. Lin, Stewart Mitchell, N. C. Raab, V. J. Richey, and C. F. Scheffey	Nov. 1
199	"Plates with Boundary Conditions of Elastic Support," by S. J. Fuchs	Nov. 1

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